

PV HYBRID SYSTEM AND BATTERY TEST RESULTS FROM GRASMERE IDAHO *

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ABSTRACT

In large PV hybrid power systems battery management is critical due to the continuous operation of the power system, the limited power available for temperature control in the battery room, and the high cost of maintenance. A new C&D CPV deep-cycle low antimony vented battery has been tested in the laboratory and at the Grasmere Idaho PV hybrid power system to evaluate battery capacity, charge requirements, temperature, and cost. Laboratory cycle tests on the battery were used to evaluate appropriate charge control for PV hybrid applications and battery field performance was verified after 2.5-years of operation at Grasmere Idaho. Test results demonstrated that with proper system and battery design using appropriate charge control, the battery will operate reliably with minimal maintenance under the continuous operational requirements of a large PV hybrid power system.

INTRODUCTION

The Grasmere PV hybrid power system is a remote electronic warfare site used by Mountain Home Air Force Base in southern Idaho (see Photo 1). This PV hybrid system was partially funded by the Energy Conservation Investment Program (ECIP) and designed by Idaho Power with support from Sandia Labs [1]. The Grasmere Idaho PV hybrid site is being monitored to evaluate the system design and components. Previous experience with photovoltaic systems identified the battery and charge controller as one of the sources for the most common performance problems and life-cycle cost drivers [2,3]. This evaluation is part of an effort to improve system design, charging strategies, and battery technology for photovoltaic systems to reduce life-cycle cost using both laboratory and field test data. Battery performance has been documented by an initial capacity test in February of 2000 and two more tests in April of 2001 and April of 2002. This work is in support of the DOE PV Balance of Systems program. It is intended to help the PV and battery industry identify appropriate PV batteries and thus reduce PV hybrid life-cycle costs.

SYSTEM DESIGN

An Advanced Energy Systems (AES) 100-kW inverter and two 210-kW diesel generators provide system power

for the 30- to 90-kW site load. A Pulse Energy DC power panel provides battery charge control for the 75-kWp Solarex PV array. The bi-directional AES inverter provides system control and power in addition to diesel generator battery charge control. The PV array is configured into six 240-volt Solarex MSX-120 subarrays tilted at 42°. The PV array typically provides about 60-kW per kW/m² of solar resource for about 21 to 29% of the total 1,047 to 1,609 kWh/day load. In this system the battery is charged primarily by the diesel generator and it is automatically programmed to bulk-charge the battery when battery voltage reaches a temperature compensated value of about 1.91 vpc and terminate bulk-charge after 3-hr at 2.35 vpc. A boost or taper-charge is provided by the generator every 6-days at a temperature compensated regulation voltage of 2.55 vpc for 5- or 6-hr. The hybrid system has been in continuous operation for about 6-years and received a new battery in December of 1999.

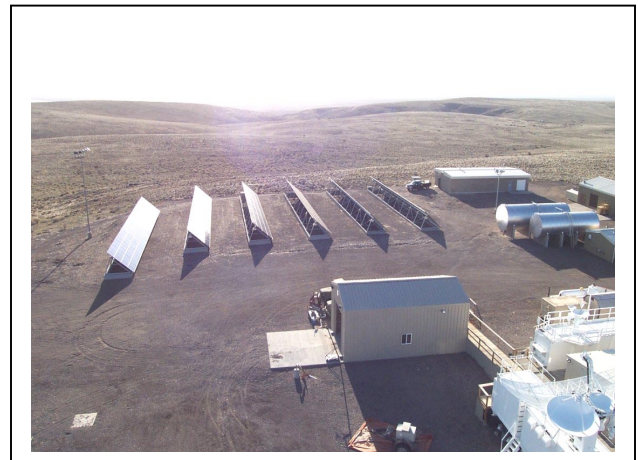


Photo 1: Grasmere PV Hybrid Site.

The new battery is a 240-volt 1.44-MWh C&D model number CPV-2340 low antimony-selenium deep-cycle battery configured in three parallel strings of 120 individual cells rated at 1,830 Ah (12-hr rate) or 2,063 Ah (24-hr rate) to 1.85 vpc (see Photo. 2). This vented battery technology is designed to generate less heat on charge and require less maintenance compared to other deep-cycle batteries by using a low antimony-selenium grid alloy, additional electrolyte reserve, and individual plastic cell trays. Battery cycle-life is rated at over 3,000 cycles to 50% depth of discharge. Each 120-cell string maintains a minimum of

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1.9-cm of spacing between each cell for heat dissipation. Cell interconnection is accomplished with two lead coated copper straps bolted to the terminal post. Each battery string uses a bolt-switch disconnect to allow for string maintenance when required. Battery discharges from – 1,600 to –1,700 Ah per string are common. At high load levels over 80-kW or low battery voltages of about 1.95 volts per cell the diesel will start to recharge the battery. Complete cycle times are 1- to 2-days without any rest periods for the battery to cool down. The diesel generator run-time averages about 9- to 13-hr/day vs. 24-hr/day without the PV hybrid power system.



Photo 2: C&D CPV-2340 Battery.

TEST RESULTS

Laboratory Test Results

Laboratory testing using the PV Hybrid Battery Cycle Test [3] was performed to answer the following questions: 1) How often does the battery need a taper-charge to maintain capacity? 2) What charge parameters are needed to maintain capacity? 3) What PV hybrid controls are needed to maintain battery capacity? and 4) What battery is most appropriate for a given system design? The test parameters include; 1) charge and discharge rate, 2) bulk-charge termination voltage, 3) discharge termination voltage, 4) taper-charge regulation voltage, 5) taper-charge interval, and 6) taper-charge time. The PV hybrid test procedure in this case makes an assumption about “typical” charge and discharge rates. It is important to understand that if system rates deviate significantly from the chosen rates, then the results may change. These rates are specified in hours required to charge or discharge the rated battery capacity. The charge and discharge currents are specified by the capacity (C) in amp-hours (Ah) divided by the required charge or discharge hours. In this case, a charge rate of C/24 and a discharge rate of C/35 were chosen to simulate a “typical” PV hybrid. If 60% of the battery capacity is discharged, then the battery would require 14.4-hr to charge and 21-hr to discharge every cycle. The resulting total cycle time would be about 1.5 days. The actual cycle time did vary due to changes in actual capacity and taper-charge time. The cycle profile consisted of 5 or 20 discharges and bulk recharges with a

boost or taper-charge at the end of each deficit-charge interval. The discharge termination voltage was 1.98 vpc or 60% DOD and the recharge termination voltage was 2.55 vpc. After the 5th or 20th deficit-charge cycle, the boost or taper-charge was provided at 2.55 vpc for 6- or 7-hr.

The results in Fig. 1 show that the C&D CPV battery will lose capacity quickly if the time between taper-charges is too long (30-days). The cycle test most like the Grasmere PV hybrid system in Fig. 1 is the second test where a 6-hr taper-charge every 5th cycle at 2.55 vpc (15.3 V) is provided. In the second test, the battery capacity drops initially 3% and then slowly fades in capacity to 91% of the initial capacity after 25-cycles. These results are similar to the initial Grasmere test results where the battery capacity dropped to 89% after 14-months. The first test configuration where the battery received a 6-hr taper-charge at 2.55 vpc every 20th cycle (~30 days) resulted in a rapid capacity loss to between 65 and 75% of the battery's initial value. The third test configuration where the battery received a 7-hr taper-charge at 2.55 vpc every 5th cycle was similar in results to the second test. The addition of 1-hr to the taper-charge in the third test resulted only a small improvement in final capacity from 91% to 94% of the initial value. The data suggests that 30-day taper-charge intervals result in excessive capacity loss, while 7-day taper-charge intervals are acceptable and result in minimal capacity loss while minimizing battery electrolysis and associated water consumption.

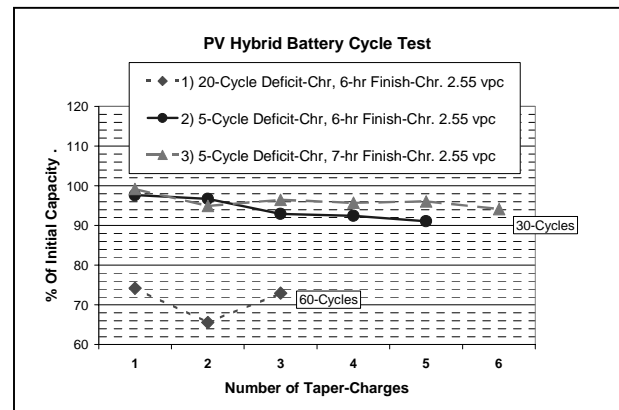


Fig. 1: Laboratory CPV Battery Test Results.

Grasmere Test Results

The Grasmere field test results obtained in April of 2001 and April of 2002, 14- and 26-months after the initial capacity test, provided the operational battery capacity after a standard 5-hr or 6-hr boost or taper-charge at 2.55 vpc. This test measured capacity under normal operating conditions of all three parallel battery strings at the 16- to 18-hr rate or –111 to –127 amps/string. The average operational string capacity was measured at 1,674 Ah at 23°C at 14-months, and about 1,846 Ah at 16°C at 26-months. The 26-month capacity is higher because of the additional taper-charge time, higher specific gravity, and the 1.75-hr long power failure in the middle of the

discharge. The power failure was caused by an inverter overload when heating loads were activated by unseasonably cold weather.

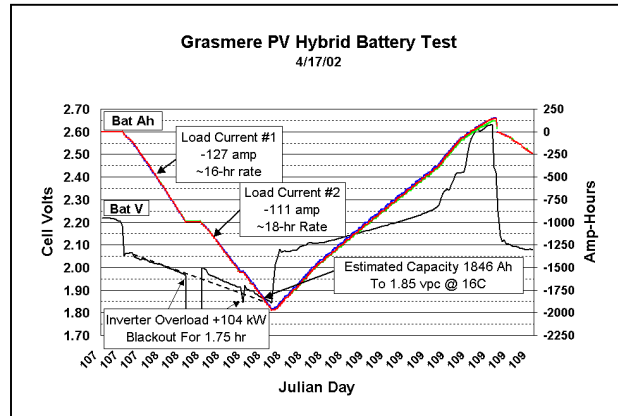


Fig. 2: Grasmere CPV Battery Test Results, April 2002.

This power failure resulted in some capacity recovery while the battery was at rest. Most of the unwanted capacity recovery was removed by projecting the discharge curve prior to the power outage to 1.85 vpc as shown in Fig. 2. The calculated temperature compensated capacity at 14-months, using 1.014 as the temperature correction factor, was about 1,697 Ah at 25°C [4]. At the 26-month capacity measurement, using 1.109 as the temperature correction factor, capacity was about 2,047 Ah at 25°C (see Fig. 2, Table 1). This is about 89% and 108% of the initial measured capacity (1,899 Ah) measured in February of 2000.

The primary cause for the initial drop in capacity was the under charging during cold winter weather and the resulting loss of battery specific gravity from an average of 1.271 in February of 2000 to an average of 1.261 in April of 2001. This 10-point drop in average specific gravity occurred even though the boost or taper-charge regulation voltage is temperature compensated at -0.005 V/°C/cell as specified by the battery manufacturer. Based on the previous years increase in specific gravity to 1.276 during the hot summer months and specific gravity measurements in September of 2001 at 1.279, battery capacity recovery does occur as a result of the hot summer weather. The increase in capacity at the 26-month point was the result of

a 6-hr taper-charge, which began in October of 2001. The additional 1-hr taper-charge was implemented to overcome under charging during the cold winter months. The April 2002 results show a high specific gravity of 1.295 and a capacity increase to about 2,047 Ah as a result of the additional taper-charge. Part of the increase in specific gravity was due to the electrolyte level being low at 1/3 of the full mark. Table 1 contains the summary battery data.

Battery Temperature

Peak summertime battery temperature after the 5-hr at 2.55 vpc boost or taper-charge measured from five cells in each string was about 41°C (see Fig. 3). The peak ambient temperature in the battery room was about 32°C. The only cooling provided in the battery room was fresh air from the ventilation system. This is a hot battery but within operational limits. The most important information obtained was the temperature of all 360 cells, which were all within about 3°C of each other. Significant temperature differences would cause severe imbalances in battery operation. An example of how sensitive the cells are to installation and ambient temperatures is illustrated by the 1° to 2°C lower temperatures measured on all end-of-string cells. These cells operated cooler because of one extra open face at the end of the battery string. The individual cells each with 1.9 cm spacing were crucial for the temperature management of the battery.

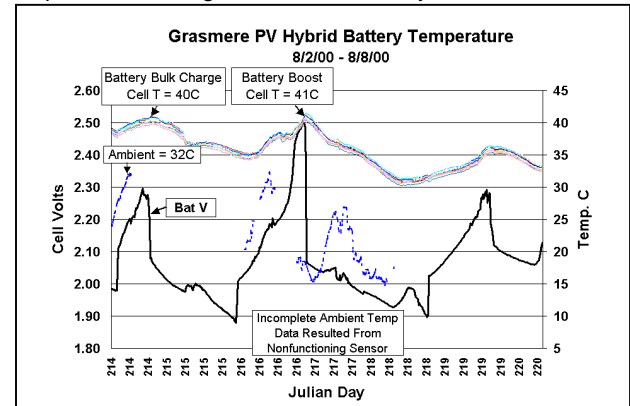


Fig. 3: Peak Summertime Battery Temperature.

Table 1: Summary Battery Data From Grasmere.

Test Date	Avg. SG	Measured Capacity Ah	Discharge Rate Amps	Battery Temp. °C	Temp. Compensated 25°C Capacity Ah	% Of Initial Capacity
2/2000	1.271	1,736	-153/-161	17	1,899	NA
8/2000	1.276	NA	NA	41	NA	NA
4/2001	1.261	1,674	-125	23	1,697	89
9/2001	1.279	NA	NA	39	NA	NA
4/2002	1.295*	1,846**	-127/-111	16	2,047**	108

*Measured when electrolyte level was low at 1/3 of full mark.

**Measured by projecting the discharge curve to 1.85 vpc before power failure occurred (see Fig. 2).

Battery Maintenance

The Grasmere battery requires an inspection with water additions every 6-months. The maintenance work includes 200 miles of travel time, battery inspection and repair if required, and manual water additions to 360 cells. If complications are not encountered, then the whole process requires about 8-hr of labor and travel time. Several unexpected maintenance requirements have occurred at the 26-month battery test. These include replacement of the flip-top vent caps and replacement of one failed cell in string-B. About 50% of the flip-top vent caps began to clog and spray electrolyte onto the battery top surface. This caused electrolyte to be lost and accelerated corrosion on the cell interconnects. The vent caps were replaced with the original orange C&D caps. If the vent cap problem was left uncorrected, then future maintenance requirements would have been greatly increased. The failed cell in string-B was identified by the low 1.000 specific gravity and 0.0 cell voltage. Fortunately, spare cells were available so that replacement was quick and relatively easy. If left, the failed cell could have overheated causing a fire or caused the battery string to receive excessive charge due to low voltage.

Battery And System Costs

Initial battery cost was about \$100/kWh for a total capital cost of about \$144,000. If the battery achieves its rated cycle-life of 3,000 cycles at 50% DOD, then the battery energy cost would be about \$0.10/kWh, not including maintenance and installation. The real value of the battery bank in conjunction with the PV hybrid system is the ability to dramatically reduce the diesel generator run time from 24-hr/day to 9-hr/day at Grasmere and load the diesel at it's at peak efficiency. The cost savings over a 20-year life using Net Present Value (NPV) calculations are significant [5]. Rough NPV cost estimates for the Grasmere PV hybrid indicate that low system maintenance and diesel fuel costs near \$0.50/liter are critical to achieving cost advantages over diesel only systems. At present, the fuel costs at Grasmere are about \$0.29/liter.

SUMMARY

The test results from this work have shown that the C&D CPV battery with proper charge control and installation can maintain rated capacity and function with a minimal amount of maintenance while maintaining acceptable operating temperatures. The initial capacity loss caused by under charging during the cold winter months was recovered by increasing the finish charge time from 5- to 6-hr. In addition, the high summertime temperatures did not cause the battery to enter a thermal runaway condition and exceed safe operating limits. Maintaining capacity while minimizing operating temperature is critical for safe reliable operation.

The most significant battery maintenance event occurred when one cell failed in string-B after 26-months for no apparent reason. Because of the individual cell

configuration and reserve cells in storage, cell replacement required only minimal effort, time, and cost. The second maintenance issue was the replacement of all the vent caps with the original C&D supplied caps because of electrolyte spraying from the clogged vent caps during gassing. This incident had minimal impact on the system because of the nonconductive plastic trays, which prevented battery ground faults and a possible electrical fire.

At present, the only operational issue is the potential loss of specific gravity and capacity over the cold winter months. The test results have shown that wintertime specific gravity and capacity can be maintained by increasing the taper-charge time by 1-hr to 6-hr total at 2.55 vpc. It was also demonstrated that the warm summertime temperatures recover lost specific gravity and probably capacity using only the 5-hr taper-charge.

NPV Cost analysis techniques show that the high capital equipment cost of PV hybrids vs. diesel only systems can be offset if the system maintenance costs are very low and the diesel fuel costs are in the \$0.50/liter range. Low maintenance costs require a significant reduction in diesel run-time and minimal maintenance on the PV array, power processing, and especially the battery. Any additional battery maintenance requirements and/or reduction in cycle-life will dramatically increase system costs.

ACKNOWLEDGMENTS

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